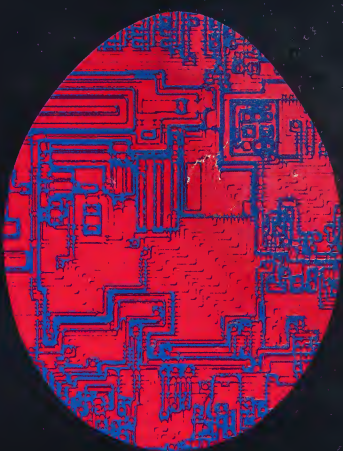
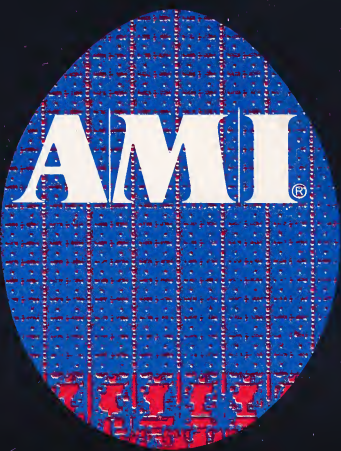
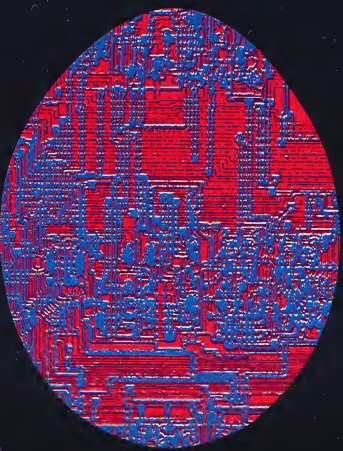
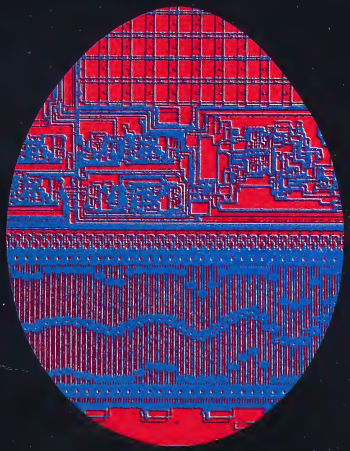
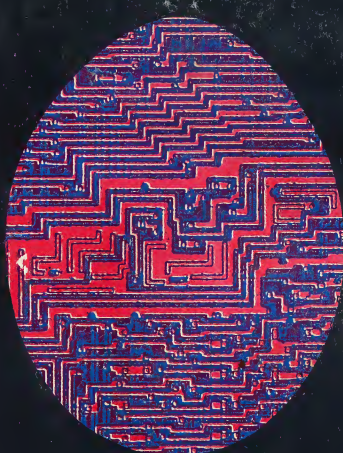
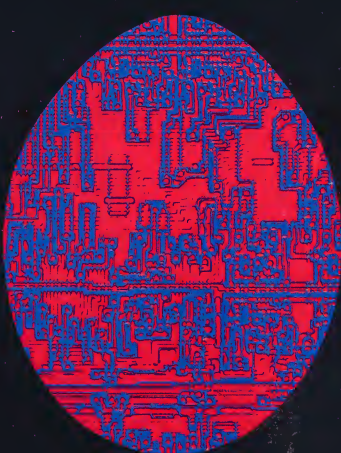
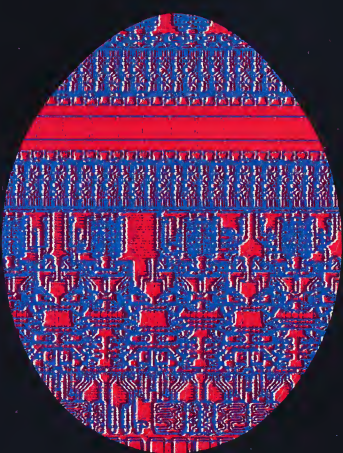
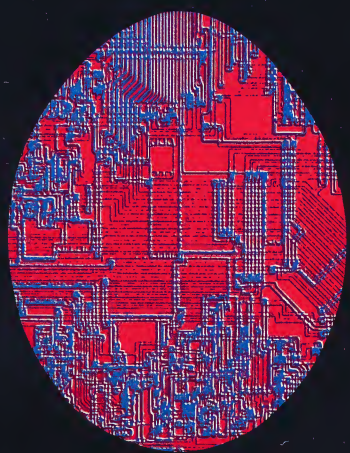
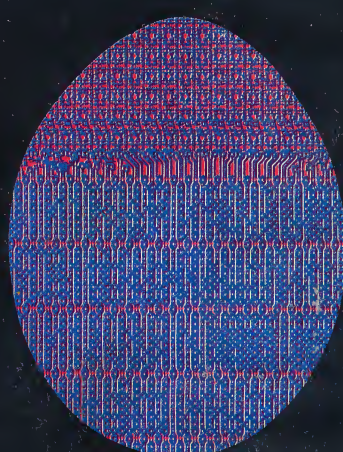
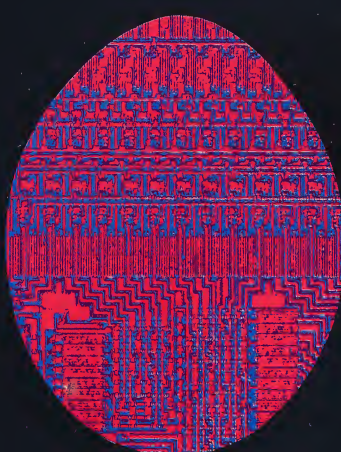
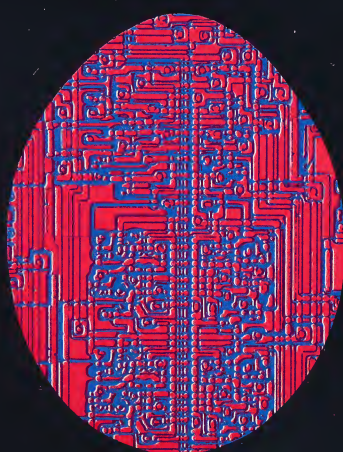


MOS Systems Solutions: A Dozen Case Histories Using Custom Circuits and Microprocessors

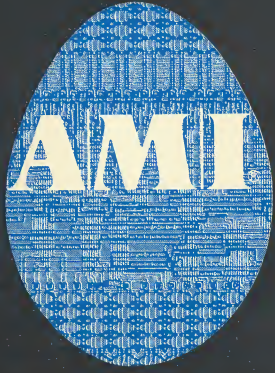




AMI[®]

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MOS Systems Solutions:

A Dozen Case Histories Using Custom Circuits and Microprocessors

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Introduction

At AMI, you find not only the world's most experienced designers and manufacturers of custom circuits, but a full spectrum of standard microcomputers and microprocessors, from low end S2000 mask programmable devices, through the very efficient S6800 to the powerful 16-bit S9900 families. In short, AMI offers you the most effective **systems solution** for any state of the art product, in high volume or low, from electronic data processing to an electronic handheld game.

From the earliest commercial uses of MOS LSI technology to the present, the custom circuit has been a principal means of maximizing overall cost-effectiveness in electronic systems. Benefits of the custom MOS LSI circuit approach include:

- Reduced system cost and improved reliability, achieved through minimized silicon area and component count; performance precisely matched to application requirements; and the ability to incorporate user-proprietary features and design concepts.
- Custom MOS LSI circuits achieve these benefits in a broad range of applications, replacing electromechanical assemblies, configurations of SSI and MSI components, and even sets of general purpose LSI circuits.

Standard, software-programmable microprocessors, with modular peripheral circuits and memories, are a more recent development. Large volume production of these general purpose components brings economies of scale to small as well as large volume users. Microprocessor modularity affords flexibility in configuring system hardware. And, software programming allows the microprocessor to be adapted to a broad range of user application requirements. Software can often be changed or added with minimum impact on the basic hardware configuration. Thus, a microprocessor-based system can be adapted to changing requirements or enhanced with new features.

The custom MOS LSI circuit and the microprocessor represent two fully complementary, and not mutually exclusive, approaches to system design. There are countless ways that they are combined to realize the benefits of both:

- Custom MOS LSI peripheral and I/O control circuitry are used with a standard general purpose microprocessor to minimize component count and optimize performance while retaining the flexibility of software programmability. This is called a "mixed" systems solution.
- General purpose microprocessor hardware is often used during system development while designs must remain fluid. Later, when the design has been fixed, part or all is replaced by custom MOS LSI circuits to maximize total system cost-effectiveness.
- The microprocessor itself is customized by adding or modifying features and the I/O interface.
- Custom MOS LSI circuits are also made programmable. Examples include true custom microprocessors and custom logic with mask-programmed control patterns that are changed like software to address different or changing application requirements.

None of these approaches is superior. The "best" approach depends on the requirements and characteristics of the individual application and must be evaluated from a total system point of view.

Since its formation in 1967, AMI has been the industry's leading supplier of custom MOS LSI circuits, and remains so today. In addition, AMI also has a broadly based line of microprocessors—including its proprietary S2000 and S3000 lines of single-chip microcomputers and the popular S6800 and S9900 families of general purpose microprocessors—with a full range of compatible peripheral circuits and memory. We are, thus, uniquely positioned in the industry to support the full range of MOS LSI system solutions, from pure custom circuit approaches to mixed configurations to general purpose microprocessor and microcomputer applications.

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This note presents a number of case histories that illustrate how AMI products—custom and standard processor and memory components—have been used by our customers to implement system solutions best matched to the application. These case histories have been chosen to illustrate the latitude of system solutions possible using custom MOS LSI circuits with (or instead of) standard microprocessor products, the criteria for selecting from among alternative system solutions, the benefits possible with different approaches, and the span of AMI products, capabilities, and services available to customers.

Mixed Custom Circuits and Microprocessor Systems

In “mixed” systems, standard microprocessor and memory components are combined with custom MOS LSI circuits to maximize total system cost-effectiveness and minimize component count while retaining the benefits and flexibility of software programmability.

The most common use of custom MOS LSI circuits in microprocessor systems is to minimize component count by integrating I/O interface and control logic functions. This often has the added benefit of improved system performance. For example, even where the microprocessor and memory configuration is entirely conventional, associated I/O interface and peripheral control logic must often be configured specifically to meet individual application requirements, which can vary significantly. Despite the growing

number of standard LSI microprocessor I/O and peripheral control support circuits now becoming available, many additional SSI, MSI and discrete components may be required to adapt these parts to a specific application. These supplemental functions and miscellaneous random logic can account for a large fraction of total system component count.

Associated with each component is not only its own direct cost, but also the collateral costs of testing, inventory, PC board size, assembly, and incremental power supply load. These collateral costs typically add another 25% to 50% to the basic material costs. One or a small number of custom MOS LSI circuits can replace most of the supplemental and miscellaneous logic in a microprocessor system and thus substantially reduce component count and associated costs, power supply requirements, and equipment size. Moreover, because system reliability is closely related to component count, it, too, is significantly improved.

The use of custom MOS LSI circuits to reduce component count and realize associated benefits is not limited solely to supplemental and miscellaneous logic. Standard microprocessor I/O and support circuits are intended to be general purpose and modular. In a microprocessor system configuration designed for a specific application, it is often possible to replace a set of such components with a smaller number of custom MOS LSI circuits. Custom implements only those I/O and peripheral control functions actually required and, in addition, incorporates supplemental and miscellaneous logic to minimize requirements for external SSI, MSI and discrete components. Even where resulting component count reduction is small, elimination of unused functions and associated silicon area can produce substantial cost savings at the systems level.

Of particular interest here are AMI's linear circuit capabilities, which allow analog-to-digital and digital-to-analog converters as well as other linear and analog processing functions to be integrated with digital logic in custom MOS LSI circuits designed for use in microprocessor system configurations.

Summary

Since the introduction of the first crude programmable LSI products in 1971, microprocessors have evolved rapidly into the broad lines of sophisticated and flexible products available today. Microprocessors have become pervasive—they are found in increasing numbers in an almost endless variety of applications. Far from shrinking the need for custom MOS LSI circuits, however, microprocessors have actually opened up vast new application areas, as the previous examples and case histories illustrate.

Microprocessors and custom MOS LSI circuits are mutually complementary. Individually, they represent two poles of a broad spectrum of system solutions available to a designer. These possibilities range from general purpose microprocessors through application-specific microprocessors, mixed custom circuit and microprocessor systems, and customized microprocessor products, to fully custom circuits. Further, custom circuits can be pure random logic or can themselves incorporate software programmability to yield the same kinds of flexibility normally associated with catalog microprocessors. In choosing from among alternatives, the key is to determine which best meets overall application requirements from a total systems viewpoint.

AMI has always been the industry's leading supplier of custom MOS LSI circuits, and we are committed to maintain that leadership in the future. In addition, AMI offers a broad line of microprocessors and associated I/O interface, peripheral control, and memory products. These span the full spectrum from the S2000 family of low-end application-specific single-chip microcomputers to the general purpose S6800 and S9900 families of products.

This combination of a strong custom circuit capability, a broad line of standard microprocessor and memory products, a firm commitment to systems approaches, and the experience to back it up are unique in the industry. As a result, AMI has become the leader in creative MOS LSI systems solutions.

Another important use of custom MOS LSI circuits is extended processing units that enhance and supplement basic microprocessor capabilities by performing complex arithmetic and numerical functions or specialized data formatting and manipulation operations. These offer substantially higher performance than emulation of the extended operations by microprocessor software, and they significantly reduce component count over hardware implementations based on TTL MSI logic. Both factors can be critical in satisfying application performance and cost requirements.

AMI regularly designs and produces custom circuits that interface with standard microprocessor systems. Several such applications are described below.

Custom Chips to Free Up Microprocessor

- Game system uses three custom chips with Z80
- Using custom chips frees processor cycles for other work, provides 10 times the computing power
- Custom chips relieve processor of address, data transfer and I/O functions

By using custom circuits for all repetitive operations and functions that required several cycles of a processor, a video game system freed its Z80 MPU to perform more decision-type operations, a design change that enhanced the computing power of the system by an order of magnitude.

The system interfaces with home TVs and can play dozens of different games by simple changes of 2K, 4K, and 8K ROM cartridges. The unit can be economically expanded into a full-blown home computer. The product comes with three internal games and a built-in, five-function, 24 key calculator with 10 memory slots to save reusable data.

The designers considered two alternatives to the use of custom circuits. The first would have been to use the Z80 for all functions. This would have required more processing time and would have resulted in less computing power for a given video game.

The other alternative was to use a discrete hardware implementation consisting of 600 standard SSI and MSI packages. This approach would have resulted in significantly higher costs, greater assembly complexity and a lower reliability with a greater number of field failures.

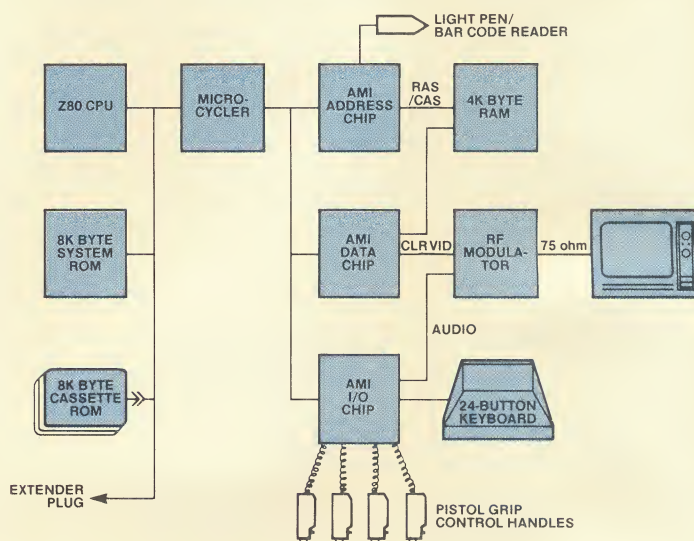


Figure 1. Block diagram of game system with three custom IC's

Three AMI custom circuits—an address, a data, and an I/O chip—provided the crucial economy and compact design of the game (see Figure 1). The **address chip** generates the scan address for screen display of the RAM and multiplexes that with the computer address. It generates all addressing functions including row and column address strobe. It also generates light pen interrupts. The **data chip** modifies data from the MPU for the purpose of video processing to the RAM and converts data from the RAM to the video stream. The address chip combines with the data chip to form the most powerful video processor available to date in custom form. The **Input/Output chip**, which is independent of the other two, is basically a series of input and output ports for the purpose of sound generation output and keyboard and analog input.

All of this means that when you come to AMI for a custom integrated circuit, you draw upon the expertise of the most experienced custom circuit designers available anywhere.

AMI customer engineers can assist you in preparing a request for quotation and can respond to your request with detailed, reliable information. AMI is the most experienced custom MOS LSI circuit manufacturer in the world, and we can give sound assistance in determining the feasibility, cost and time required to develop a custom circuit for almost any application.

Among circuit design considerations AMI can assist you with what is the best option to select:

- **Whether to use custom circuits, a mixed custom circuit and microprocessor approach, or general purpose or application-specific microprocessors**
- **Whether to have AMI design the circuit for you entirely**
- **Whether to perform the design cooperatively between you and AMI**
- **Whether to use a "customer tooling" approach (i.e. design your own circuit and have AMI fabricate it)**

Custom Costs

Custom chips for microprocessor applications can be simple or complex, easy to fabricate or difficult. As a consequence, the costs are individually negotiated and based on factors that vary from chip to chip.

Circuit size, functional complexity, operational speed, operating temperature, processing technology, special reliability tests, quality assurance programs, quantity and delivery schedule go into determining the ultimate price per chip.

AMI Support for Microprocessor System Solutions

AMI provides broadly based lines of microprocessors, microcomputers, associated peripheral and I/O control circuits, and supporting memory for systems solutions based on general purpose or mixed custom circuit and standard product configurations. AMI is a full line supplier of the popular, industry standard S6800 line of mid-range microprocessors, microcomputers, and support circuits, and continues to extend the line with products such as the S68047 Video Display Generator. For high-end applications, AMI supplies the powerful S9900 family of 16-bit microprocessors.

AMI application-specific microcomputers, described in a preceding section, include the S2000 family of low-end, single-chip microcomputers addressed to appliances, toys and games, and similar control applications; the S3000 single-chip CMOS programmable time keeping processor; and the powerful high-speed VMOS S2811 signal processing peripheral.

AMI memory products designed for microprocessor applications include conventional N-channel ROMs, and VMOS memories for the newer, high performance microprocessors. The latter include high-speed 16K and 64K ROMs and 1K x 4, 1K x 8, and 2K x 8 fully static RAMs.

AMI also provides complete microprocessor development system hardware and software support tools through Millennium Systems, Inc., a wholly owned subsidiary. A fully staffed group of experienced applications specialists is available to aid in selecting and configuring the most cost effective systems solution. Contract programming services are regularly provided by AMI or through outside specialists. AMI can also arrange to supply fully assembled modules through any of several established suppliers with whom we have working relationships.

Systems design engineers supplied AMI with three CMOS breadboards at the start of the project. AMI implemented the breadboard logic and further reduced the system parts count by pulling more external components onto the custom circuit. This required a significant joint effort during the logic generation phase and the development of a second breadboard. Due to the complex processor control, the customer was also involved in the development of the test program. Simply stated, the customer knew a lot about the system interaction while AMI knew the internal operation of the custom circuits.

This development took nine months to produce working prototypes and four additional months to achieve full volume production.

Custom Interface Between MPU and Machine Tool Motor Controls

- Custom logic and memory circuit stores intermediate program steps
- Chip interprets position sensor input and activates motor controls
- Eliminates several dozen discrete components and TTL circuits
- Increases reliability, decreases system size

In another "mixed" solution, an AMI custom circuit simplified and improved a design by combining logic and memory in an interface between a microprocessor and the motor controls of a numerical control system for lathes and milling machines. The controls permit mass producing machined parts. A single custom circuit combines random logic and RAM to store intermediate program steps, interpret laser sensor data from the machines, and control the motors that position workpieces and cutting heads in the machines (see Figure 2). In all, the custom circuit contains 3,975 logic gates. System program control is by interchangeable ROMs. To alter what a machine does, an operator has only to remove one ROM and insert another. A RAM program memory was also included so that special requirements could be entered by the operator via keyboard.

The original engineering mockups of the system required several dozen logic gates and memory chips to perform the functions of the simple interface circuit shown in the block diagram. Utilizing a custom circuit reduced component insertion costs, decreased printed circuit board size, greatly improved reliability, and lowered maintenance and downtime of the system. Through use of a custom circuit, hardware cost of the MPU interface was reduced approximately 50 percent, before calculating costs saved by reduced maintenance complexity and increased reliability.

The development cost for this interface circuit was approximately \$90,000. This amounts to about \$1.00 per chip over the entire five year production lifetime of the system.

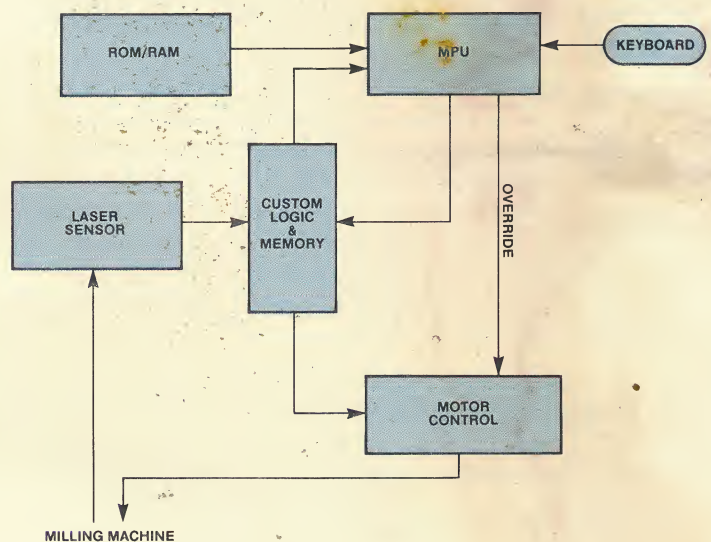


Figure 2. Block diagram of machine tool controller with custom IC

AMI participated in both system definition and circuit design, acting as a consultant on the logic, system and circuit specifications. The customer developed the system block diagram, and AMI designed the custom interface to fulfill his requirements. The span time, from system conception to first custom circuit delivery was about a year.

The **AMI S3000** is a CMOS programmable chronometer specifically designed as a standard product for use in watches, clocks, and a broad range of timing applications. Like S2000 family microcomputers, the S3000 incorporates on-chip the I/O interface and control logic required for most applications.

The **AMI S2811** signal processing peripheral (SPP) is a specialized, high-speed, VMOS programmable numerical processor. For example, it is able to multiply two 12-bit numbers and add the 12-bit truncated product into a 16-bit accumulator, all in 300 ns. The S2811 architecture, processing speed, and on-chip features have been designed specifically to meet requirements for digital signal processing in telecommunications applications such as echo suppression, digital filtering, and modems. Other applications include fast Fourier transform (FFT) and mathematical function generation. The S2811 includes high speed on-chip ROM and RAM for program and data storage. It is designed to be bus compatible with the S6800, the S9900, and other popular microprocessor families (Figure 11).

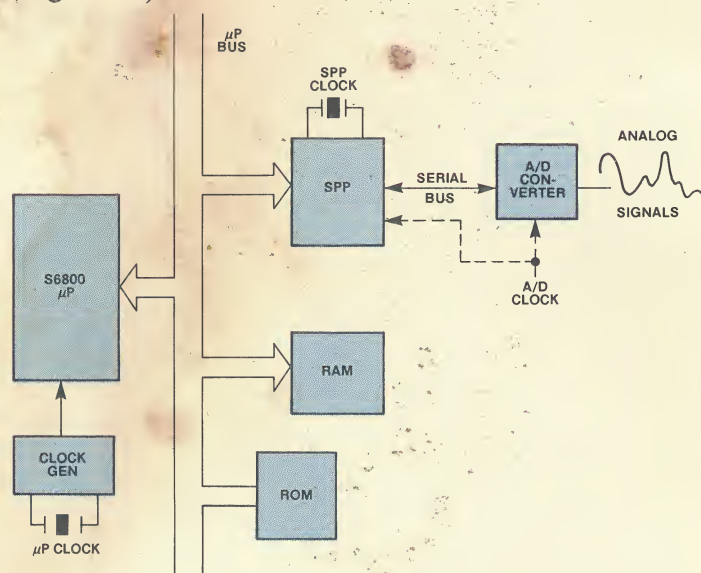


Figure 11. Minimum component modem utilizing the S2811 signal processing peripheral with a microprocessor

In designing such products, AMI employs the same high level systems approaches and applications expertise that has made it the leading supplier of custom MOS LSI. The results are products with performance and features specifically tailored to the requirements of their intended applications, maximizing overall system cost-effectiveness and minimizing total system cost.

Additional Considerations

Committing to Custom

Because the use of custom circuits involves disclosure of proprietary information, may take a relatively long period of time and requires close liaison between your company representatives and AMI, work on a custom circuit cannot be performed at arm's length. AMI understands this better than anyone. We have established tightly controlled working conditions to protect customer interests in designs. We have developed careful procedures to verify circuit logic, perform computer simulation, and obtain customer approval before committing a circuit to layout.

A number of tools and incentives have been implemented to speed up circuit layout, checking and pattern generation, and to improve the probability that a circuit will work the first time it is fabricated in silicon. Among these is a computer-aided Interactive Design System, utilizing color CRT terminals to lay circuits out symbolically, check design rules, verify connectivity, and determine circuit continuity in real time. The system eliminates the time formerly required for digitizing a hand drawn or computer drawn circuit and checking it in batch mode on a mainframe computer. In addition, there are financial incentives for the design team to produce a working circuit the first time, and to optimize it for volume production.

Custom Output Display Drivers

- Provide unique display features
- Simplify circuit design and field maintenance
- Offer non-standard line lengths or display sizes
- Satisfy operational space or packaging constraints

AMI has designed numerous display drivers that interface a microprocessor to LED, LCD and vacuum fluorescent outputs. An automotive application, for example, contains an LED display driver interfacing a 6800 microprocessor to the dashboard instrument cluster display.

For an appliance a 32-bit, 4-digit universal display driver was developed. This P-channel MOS LSI circuit was a better alternative than bipolar display drivers because of the lower current drain, and better than TTL MSI drivers because of lower component count, lower total cost and higher reliability.

The universal display driver was completed in 21 weeks, from design start to successful operation of the first silicon. The customer provided the circuit specifications and AMI developed the logic. (It should also be noted that the customer has given AMI the rights to sell this part as a catalog product with the expectation that the added volume will lead to lower unit prices for the original customer.)

I/O and Timing Circuits for a CRT Display

- Custom circuits satisfy product compatibility requirements for odd-size data characters
- Reduce inventory and spare costs
- Reduce power requirements, cooling and enclosure costs
- One custom circuit provides 25 options for CRT screen format

A manufacturer of IBM-compatible terminals utilizes custom I/O and timing chips as a means of standardizing components within a product line and retaining compatibility among them. This approach minimizes inventory and quality control problems and reduces product design costs. Because IBM data characters have an 11-bit length, standard microprocessors do not handle

them well. To retain compatibility with other equipment handling the IBM format, the data character length cannot be changed, and custom chips represent the most effective means of meeting the system requirements of the terminals.

The company had the I/O chip designed as a specialized UART (Universal Asynchronous Receiver-Transmitter) capable of operating in a full-duplex mode (see Figure 3). The chip receives data serially in the 11-bit pattern, loads it into an input register, decodes it to eight data bits and places it on the internal data bus for transfer. To transmit, the custom chip removes data from the internal bus, adds the parity bit, clock pulses and start/stop bits and outputs it to the serial line. The device also includes an interrupt timer and the required control and status registers.

A standard UART could not have handled the operation without serious modification or paying penalties in data handling efficiency.

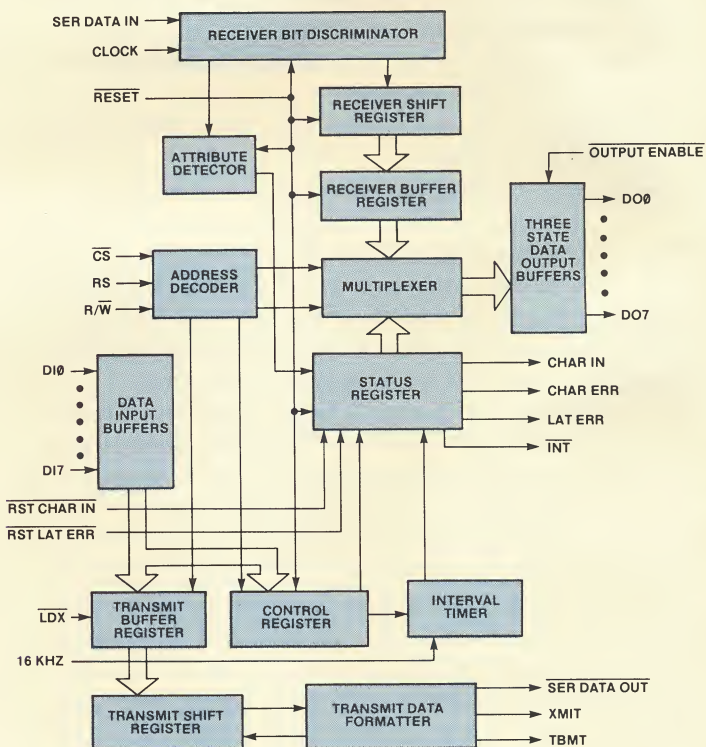


Figure 3. Block diagram of the custom I/O microcircuit used in a CRT Display Terminal

Application-Specific Microprocessors

Most conventional microprocessor product lines are modular designs for general purpose use. Architectures, memory organizations, instruction sets, and other on-chip features are intended to serve a broad range of user requirements. In recent years there have emerged identifiable categories of applications characterized by very similar microprocessor system requirements. Some of these application categories represent sufficient cumulative market potential to justify special purpose, standard product microprocessors designed specifically to address their particular requirements. Like general purpose products, these application-specific microprocessors bring economies of large scale production to both small and large users within the addressed application category. Like custom MOS LSI circuits, application-specific microprocessors result in a lower component count and lower system cost than would normally be possible using general purpose, modular microprocessor products.

AMI has pioneered in developing application-specific microprocessor products, beginning with custom and extending into standard products. AMI standard products include the S2000 family of single-chip microcomputers, the S3000 CMOS single-chip programmable timer, and the S2811 high-speed VMOS signal processing peripheral (SPP).

The **AMI S2000** family of single-chip microcomputers is designed specifically for controlling appliances, automobiles, home heating and cooling systems, office equipment and other consumer products. It is also ideally suited for use in toys, games, and a variety of other low-end control applications. S2000 family microcomputers feature a 4-bit architecture, on-chip RAM and ROM, and also incorporate most or all of the I/O

interface and control logic required for the applications they are intended to serve. On-chip features of the S2000 and S2150 (Figure 10) include TouchControl™ capacitive switch interface, zero-crossing detection, 50Hz/60Hz timer, 7-segment display decoder, and LED display drivers. To these features, the S2200 and S2400 add 8-bit analog-to-digital conversion, interrupts, and more. These and other S2000 family on-chip features are in addition to the general purpose I/O normally found on conventional low-end single-chip microcomputers. Because so many of the required features are incorporated on-chip, S2000 family microcomputers typically require far fewer external components than other, more general purpose low-end microcomputers in systems configured for the targeted category of applications. As a result, total systems cost is reduced, in many cases substantially.

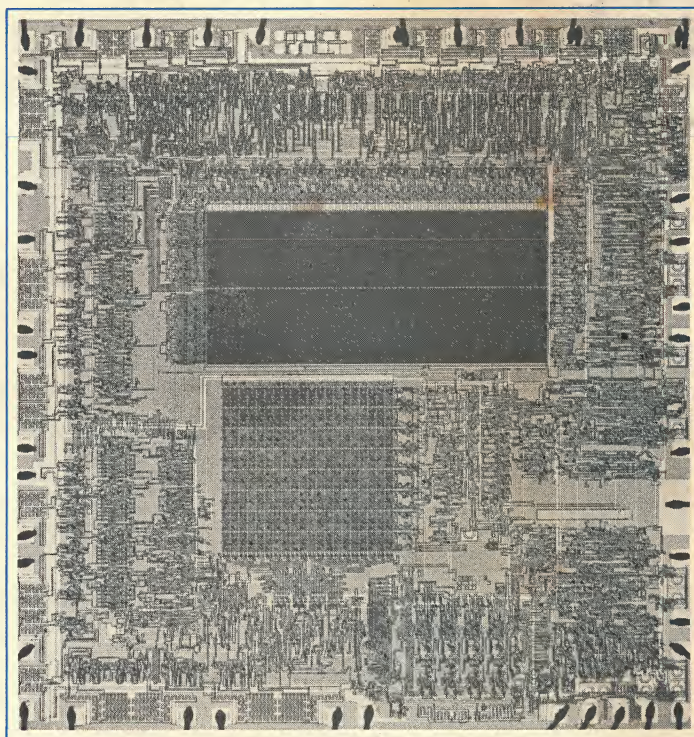


Figure 10. S2150 4-bit microcomputer circuit

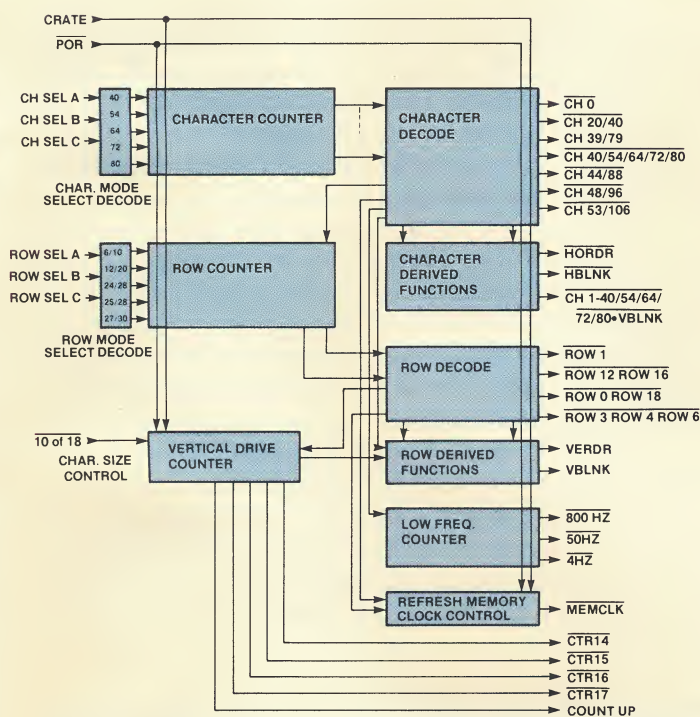


Figure 4. Block diagram of the custom timing microcircuit used in a CRT Display Terminal

A custom timing chip performs all timing operations for terminal CRT displays (see Figure 4). It handles both horizontal and vertical sweep signals and blanking. It also does the display housekeeping and permits 25 options as to screen format, with five different line widths and five different column lengths.

Other advantages, beyond the incorporation or combination of special features in a single custom chip for a number of products, are the common advantages of custom design—reduction of system power requirements, lower cooling requirements and smaller printed circuit board sizes. The company in fact realized improved product reliability because integrating numerous functions in the two chips eliminated about two dozen components in the final designs. Mean time between failure with custom chips is considerably greater than for the earlier system.

As a bonus, the custom chips lowered internally generated heat, and allowed the company to use a less expensive product enclosure.

Custom Chip Together with a Microprocessor Generate Secure Messages

- Custom chip supplies unique codes and pseudo-random keystream
- Reduces power requirements, to make device handheld, battery operated
- Protects code secrecy, product proprietary design

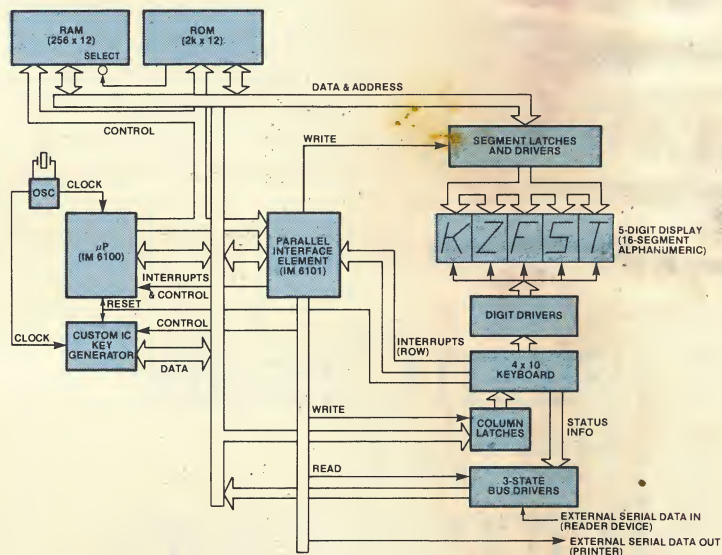


Figure 5. Block diagram of a handheld message encrypter with custom IC

Sometimes, the uniqueness of a system **absolutely requires** a custom design. A company that manufactures coding equipment uses a MOS LSI chip under microprocessor control to perform the encryption and decryption functions for a handheld cryptographic device (see Figure 5). The microprocessor handles the keyboard scanning tasks and display control, using ordinary software algorithms. The custom chip, designed for bus compatibility with the microprocessor, then

Development cost for the three circuits approached \$250,000. Two of the circuits are over 200 mils on a side. All operate at a frequency of 4.5MHz. The entire system has about 13,000 non-ROM transistors and about 22,000 ROM type devices. Production is expected to run several hundred thousand sets over a multi-year period.

For purpose of comparison, the system was benchmarked against a catalog microprocessor system. Because of the specialized instruction set, the custom system required approximately half as much ROM code as the catalog system to implement typical engine control algorithms. In addition, the throughput rates of the custom system were about twice that of a catalog microprocessor system. The custom system required only three N-channel chips, whereas a catalog system would have required six CMOS chips.

Custom Microprocessor for Avionics

- Custom circuits provide precise timing of interrupts
- Supply 200 synthesized frequencies
- Perform special repetitive calculations
- Multiplex display signals
- Reduce weight and power requirements for airborne operation

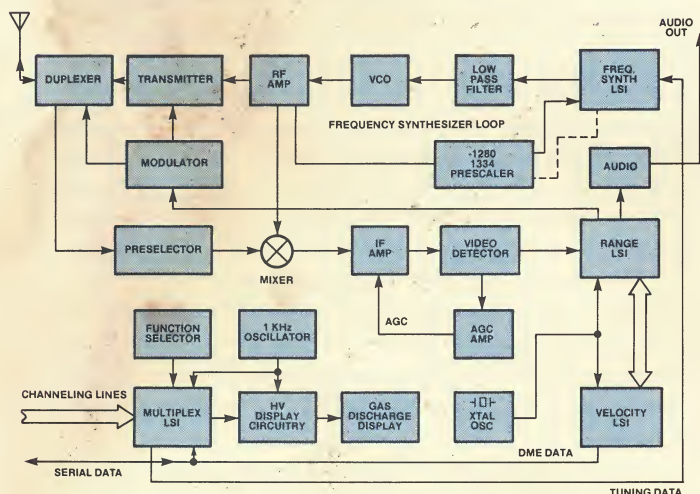


Figure 9. Airborne DME using custom chips for computing functions

Despite the flexibility and power of microprocessors, there are cases where they are simply unable to perform the required functions. In those instances, a designer must either use discrete components or find a custom solution to his problem.

One such case lies in the design of an airborne system for measuring the distance of an aircraft from a ground transmitting station, and the time required to reach that station at the plane's current groundspeed. The system performs these measurements by transmitting pulses from the plane to a ground station transponder, which delays the pulses for a fixed period and then transmits them back.

The airborne system must be able to synthesize 200 different frequencies, time the pulses, receive the pulses exactly, time the interval between transmission and reception and compare the most recent time interval with preceding intervals. All of this is complicated enough, but the system must also occupy minimal instrument panel space and consume as little of the aircraft's power supply as possible.

Timing the intervals requires that the system handle reception of interrupts in exactly the same number of steps each time. No standard microprocessor could do this, nor could any operate at the clock speeds required to measure the tiny intervals between transmission and reception of the distance-measuring signals.

As a result, system designers turned to custom MOS LSI circuits to solve the problems of processor speed, system size and power consumption. They designed four chips—a frequency synthesizer, a range calculator, a velocity calculator and a display multiplexer—that allowed them to build a system occupying only eight square inches of panel space and weighing less than two and one half pounds!

These circuits were designed by the customer and AMI fabricates the devices. AMI design rules and manufacturing specifications were provided to the customer during the design phase.

supplies up to 10^{52} selectable codes for specific messages. The chip can generate a pseudorandom keystream up to 10^{65} bits long. Output of the custom chip is mixed in the microprocessor with the keyboard input to produce the final coded or decoded message.

*Custom design and fabrication provided the uniqueness required for this extraordinary product and permitted the company to select the lowest power-consuming LSI technology, CMOS. During the product design phase, MSI solutions were considered. However, they would have required 100 components and a large power supply. Using the custom chip, the final design is no larger than a handheld calculator and operates on a nine-volt battery.

To protect the encryption algorithm, the manufacturers themselves designed the custom chip and came to AMI for wafer fabrication. This gave the customer control of the design phase as well as protection of the proprietary details of the circuit.

Custom Circuits to Replace Microprocessors

Custom circuits or custom modifications sometimes replace standard microprocessors. Once a microprocessor-based system has achieved the desired feature set and performance specifications of the application are established, the inherent flexibility of the microprocessor may no longer be needed. Microprocessor capabilities often exceed the needs required of a specific application, and the customer pays for that overkill in every production unit.

Often, a better solution is to use a microprocessor during the design phase, while feature sets are fluid, and to switch to a custom circuit once the design is fixed. This is particularly effective in cases where product cost is critical, where unit volume is high, and where lead time is sufficient to allow for custom circuit design.

Quite often, a microprocessor does not quite fit an application. There may be too much I/O or an A-to-D conversion is needed external to the microprocessor, or the control function does not really require full microprocessor power. In such cases, a custom circuit represents a better and lower cost approach.

As a supplier of both custom circuits and a full range of standard microprocessors and peripherals, AMI offers valuable expertise to help the customer decide which approach is best for him. Following are some applications for which AMI has designed circuits to be used in lieu of a microprocessor.

Custom Controllers for Sewing Machines

- Custom circuit integrates electronic controls in single IC package
- Provides highly flexible stitch types and sizes
- Saves space over electromechanical or standard components
- Simplifies operation, maintenance

The world's first electronic sewing machine utilized an AMI P-Channel LSI custom circuit to offer 24 preprogrammed types of stitches, increase the ease of operation, and eliminate 350 mechanical parts. Conventional mechanical sewing machines require the operator to change a set of geared cams to alter the stitch type. Lengthy step-by-step instructions on how to use the cams and other attachments are necessary.

With the cam system, only fixed stitch lengths are possible. With custom, electronic control permits more stitch sizes and types.

Custom Circuits for a Small Business Computer

- Custom circuit meets extraordinary space restrictions
- Assures interproduct compatibility
- Reduces software development and maintenance costs
- Decreases power and ventilation requirements, system noise

Constraints of system size and the need to retain compatibility with already developed software led one large computer manufacturer to use custom chips in designing a line of small business computers.

Size constraints required that the system occupy as little volume as possible, and that the boards making up the system fit into unlikely locations. This is a big difference from the cabinet-housed larger systems with voluminous card cages mounted in standard 19-inch wide racks. Besides, the smaller systems pose special ventilation (and consequent noise) problems.

The solution was to use custom circuits that reduced size, permitted grouping functions to fit packaging needs and lowered the power and ventilation requirements. The result was a CPU consisting of custom circuits. The chip set is used in three different products, giving the customer a much broader base over which to amortize design costs.

Because each system is designed for modular enhancements, the company also utilizes custom chips in peripherals, as controllers for disks, keyboards, matrix printers and data communications equipment. These chips ensure compatibility and interchangeability of hardware, system software and applications programs as the company upgrades the systems for each new generation.

Standard products might have done the job, but only through a long and costly investment in software development to ensure upward compatibility and a consequent degradation of performance, since time-consuming software would have to perform tasks that are handled quickly and efficiently by custom chips.

Custom Microprocessor for Automotive Engine Control

- Custom circuits combine high speed CPU and fast memory on chip
- Circuit provides extensive specialized I/O to handle sensor inputs and control outputs
- Special system-matched ROM

This system consists of a group of three custom N-channel silicon gate circuits which provide control of ignition, fuel injection and exhaust gas recirculation, and includes transmission control. The system was constructed based on conventional computer architecture, customized for engine control. One chip comprises the CPU and fast memory. A second chip contains the extensive I/O required to measure engine parameters and control engine response. The third circuit provides the fixed ROM data which customizes the set to a particular application.

The custom approach was selected because no standard system was available that could meet the cost, functional complexity and operating performance. The part must be capable of operating in a 125°C environment.

The initial phase of the development was a system-requirements/technology-limits study. During this phase, critical decisions were made regarding the level of chip complexity (number of gates) allowed versus economic chip sizes, propagation delays achievable versus system clock frequency, and interface and power supply voltage levels. This phase concluded with a rough chip partitioning, die size with unit cost estimates and development costs and schedules. The decision to proceed was based on the results of this study.

The three circuits took approximately 20 months to develop from the beginning of the initial phase to the shipment of the last of the three prototypes. The three circuits required respectively three, two and one redesigns to achieve full performance.

A second source was arranged by permitting another semiconductor company to use AMI tooling.

Key to simplicity of the machine's operation is the stitch selector panel (see Figure 6). Each pattern, individually programmed in the AMI chip, is graphically displayed across the panel. An operator rotates a dial to center the desired pattern above one of six control buttons. Touching that button selects one of 24 stitch patterns.

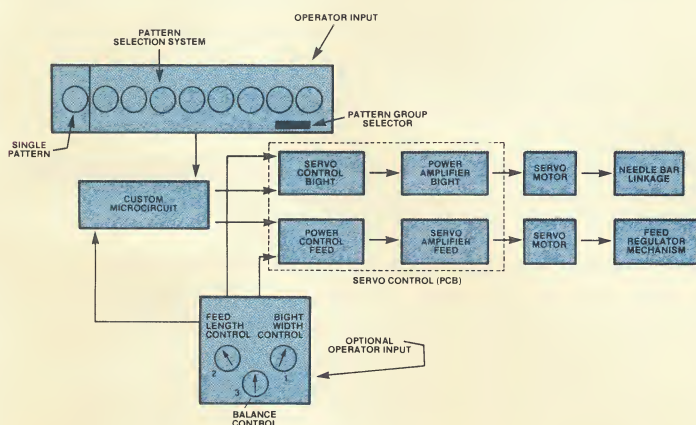


Figure 6. Electronic sewing control system with custom IC

The custom chip is primarily a ROM (read-only memory) circuit that permanently stores the instructions for sewing the 24 different patterns. The ROM, which can store 6,000 bits of information, also controls the sequences of variable length pulses that are converted to analog voltages by an off-chip filter and flow to the actuator. (If the chip were redesigned now it would be possible to include the filters on chip.) The actuator, which creates the pattern, consists of two linear servos that control the needle's bight (left to right movement) and the back and forth movement of the fabric.

Besides the ROM, the microcircuit contains shift registers for temporary data storage, an inverter and RC oscillator circuitry that provide clock reference timing to the chip for accurate pulsing and proper sequence of the logic flow. Safety logic circuitry on the chip prevents damage to the needle and the machine.

The customer and AMI worked together over a period of several months to produce the custom design. Designers initially used a computer simulation to develop the logic. When they demonstrated that computer logic could perform the desired functions, the MOS LSI circuit design began, using AMI's design rules and manufacturing standards.

After the successful introduction of a top-of-the-line machine, the customer's design team returned to their drawing boards to come up with a lower cost consumer version.

At roughly two-thirds the price of the first machine, the second featured 14 stitch patterns programmed in memory and selectable at the touch of a button. As with its predecessor, the key to the new electronic design was another custom microcircuit which helped eliminate 145 mechanical parts.

Reuse of the first custom circuit to perform a repertoire of functions was considered; however, it proved to be more cost-effective to design a smaller, less expensive custom circuit rather than to include the under-utilized larger circuit in the lower cost machine.

For both sewing machines, designers rejected off-the-shelf microprocessor control because that would have meant using as many as five microcircuits costing many times more than a single custom circuit. With a design dedicated to the specific application, the custom chip had the fewest possible circuit elements and was, therefore, more reliable and less expensive. The development cost of the custom chips was considered very reasonable relative to the benefits desired. Because the control logic of these custom circuits was driven by mask-programmed ROM patterns, the same kind of flexibility inherent in a software programmable microprocessor was achieved.

the on-chip functions, these were eliminated to create space on the silicon die for the larger drivers.

In addition, the customer wanted the S2000 to generate sounds for the game. To accommodate this special circuitry, an on-chip divide-by-60 counter was removed (the game was battery-powered and did not use the counter), and a programmable divide-by-N was added to gate an on-chip audio oscillator. The resulting modified S2000 can generate hardware controlled sound precisely as the customer requested. The several hundred byte program that would have originally been required to generate the sound through software was reduced to ten bytes through hardware modification. The microcomputer die size remained exactly the same as that of the standard product.

An S2000 with High-Voltage Display Drivers

- Added direct high voltage drive of vacuum fluorescent display
- Minimum cost for powerful feature advantage

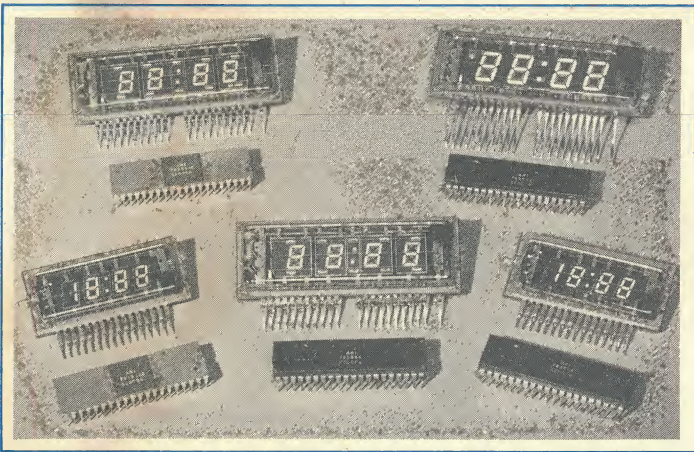


Figure 8. S2000A microcomputer modified to drive high voltage display

For a different customer, AMI redesigned the S2000 to drive a vacuum fluorescent display. The customer wanted to upgrade its product to utilize an N-channel microprocessor and found no microprocessor available that could drive high voltage displays. Having selected the S2000 for the upgrade, the customer asked AMI to customize the device to drive the display.

After a short research program and development of a test chip, AMI produced the first N-channel microcomputer that can directly drive a high voltage vacuum fluorescent display (Figure 8).

Each of these custom modifications cost about \$40,000 and took approximately three months to develop. Both display drive and sound generating features are now available as special-purpose standard versions of the S2000 family of products.

Custom Microprocessors

In contrast to a customized microprocessor, a truly custom microprocessor typically consists of unique architecture, word length, instruction set, and may well require its own specially developed support systems. Because of the extensive development cost, custom microprocessors are only employed in those cases where (1) special software programming features and capabilities are required, (2) the application is truly unique and cannot be adequately accommodated by a catalog microprocessor, and (3) the volume is sufficiently high to warrant the development expenditure. AMI does, however, produce custom microprocessors, two of which are described below.

Custom Circuit for Automotive Instrument Cluster

- Custom circuit satisfies space, power consumption restrictions
- Custom-tailored reliability program meets auto manufacturers' stringent demands
- Provides saleable feature at feasible cost
- Protects proprietary design

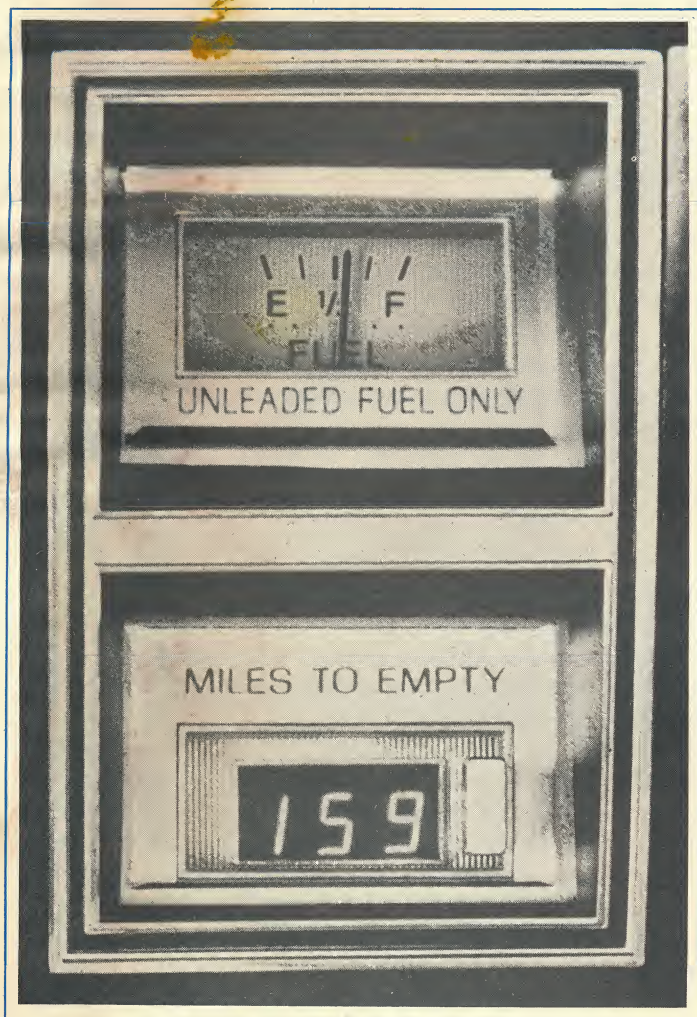


Figure 7. Miles-to-empty indicator in automobile dashboard

An automobile manufacturer turned to custom circuits as a means of building a system for reporting the number of miles available from the gas remaining in the tank (see picture of display in Figure 7).

Here the manufacturer wanted a simple, low-cost system that could meet the stringent demands of automobile production, testing, installation and replacement in the event of failure. The final design had to fit into a very small space, enjoy high reliability and be readily producible to schedule.

Though a microprocessor could have handled the job, peripheral circuits and system components quickly increased costs, complicated testing, and lowered reliability and took up too much space in the instrument cluster. MPU capabilities greatly exceeded what the task demanded.

Working with AMI designers, the company developed a custom circuit that combined logic, I/O and memory for the system on a single chip. The engineering prototype contained more than 100 components; the final circuit fits into a 26-pin plastic package with a volume of about one-quarter cubic inch.

By selecting a mature MOS LSI technology for fabrication, the circuit designers achieved high production rates, excellent in-service reliability and easy circuit fabrication to meet the automaker's tight production schedules. A high reliability program during manufacture at AMI assures reliability performance on the road. Because most of the system resides in the custom circuit, the automaker's receiving, in-process and final testing are greatly simplified.

In this instance, custom MOS LSI delivered benefits unavailable with other solutions.

Custom Circuits Provide Competitive Edge for a Telephone Tone-To-Pulse Converter

- Custom circuit provides cost competitive edge for company's market entry
- Converts station equipment to push-button with changing high cost central office equipment
- Offers flexibility in adapting products to customer requirements

Custom circuits frequently offer a way to successfully enter an existing market by giving products a better feature set or a lower price.

An example is the telephone equipment market, where converters are used to change push-button tone inputs to dial pulses for processing in conventional electromechanical central office switching systems. Although telephone users prefer push-button dials over rotary dials, it is not feasible to convert all central offices to electronic switches immediately. One solution is to use key-to-pulse converters.

One company entered the tone-to-pulse converter market using custom MOS LSI circuits. Custom chips enabled the company to design small units that fit comfortably into older central telephone office racks. These state-of-the-art custom-based systems successfully compete with earlier discrete-component conversion unit systems on the basis of size, cost, power, reliability, and ease of test and maintenance.

The custom MOS LSI circuits also adapt well to OEM subsystems destined for use in PABXs and other telephone control systems. The circuits have maximum flexibility so that the company takes advantage of just such opportunities. For example, there are pads for 42 internal bonds to the 40-pin integrated circuit package. Simply by changing the bonding configuration, the company can alter the feature set supplied by that chip.

This custom circuit provided the company with a competitive edge in product features and cost. As a result, the company achieved a significant position in this market.

Customizing Catalog Microprocessors and Peripheral Circuits

In many situations, a microprocessor satisfies the application requirements, but a custom modification can add attractive features or capabilities and improve performance or reduce cost. Possible modifications include:

- **Addition of A/D or D/A converters**
- **Different partitioning of RAM and ROM**
- **Special signal processing or conditioning**

The user should realize that it may be difficult to modify many microprocessors where size and circuit topography have already been optimized to reduce cost. In addition, the customization may only be economically justified if a large volume of circuits is anticipated. AMI invites inquiries about such modifications. We have modified the S2000 4-bit microprocessor for several applications, two of which are described below.

Modified S2000 Microcomputer for a Handheld Game

- **Increases size of directly driven LED display**
- **Eliminates unnecessary circuitry**
- **Adds audio signal generation capability**
- **Reduces program memory consumption, enables additional features**

In one case, a customer wanted to use AMI's proprietary S2000 single-chip microcomputer in a handheld game, but the device could not directly drive the large LED array desired by the customer. AMI agreed to modify the chip's display driving circuitry to increase its drive current capability. Since the customer did not need some of